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TOWARDS A PRACTICAL WARNING SYSTEM FOR FIRE BLIGHT BLOSSOM INFECTION

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Summary

A system is proposed to evaluate the relative risk of the occurrence of severe fire blight in particular orchards in any given season. This system could be used as a basis for recommending the application of bactericide sprays to prevent blossom infection. The system takes into consideration factors peculiar to individual orchards, which affect host susceptibility and the availability of inoculum, and weather conditions, which affect the dissemination and multiplication of *Erwinia amylovora*. A tentative model has been developed that combines orchard risk and weather risk to determine overall risk of fire blight. This model will be tested and revised based on disease incidence, weather, and orchard characteristic data collected from 220 orchard blocks in New York State in 1982 and 1983.

1. Introduction

Fire blight is a sporadic disease that is severe in some orchards in some years and of minor concern in others. Much is known about the factors that determine the severity of fire blight. Observations on the development of fire blight in orchards and experimental studies have indicated that weather conditions, sources of inoculum, types of trees grown, and the conditions under which they are grown all influence the extent to which fire blight develops.

Measures available to control or manage fire blight are limited (Aldwinckle and Beer, 1979). There is no magic elixir that can be applied to provide long-lasting protection against fire blight. Instead, certain practices may be used to reduce the incidence or severity of the disease. In existing orchards of susceptible cultivars, bactericides are applied to pome-fruit flowers to prevent the development of blossom infection, which is generally the first new phase of the disease that occurs each season under northeastern United States conditions. However, applications of bactericides during bloom are not always warranted; growers frequently observe that blocks not

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treated with bactericides sustain little or no fire blight damage. Because present recommendations for the use of chemical sprays to control fire blight in New York (Riedl et al., 1983) are based mainly on predicted weather conditions and give little consideration to other factors, sprays often would be applied to orchards that would not sustain fire blight without them. Thus, a better system for determining when sprays are warranted is needed.

The purpose of this paper is to consider all the factors that affect the incidence and severity of fire blight and to attempt to integrate them into a system that will permit an assessment of the relative risk of severe fire blight in a particular block. Weather conditions are used to determine "Weather Risk" and factors peculiar to individual orchards are used to determine "Orchard Risk". The "Overall Risk" of fire blight is considered to be due to the combined effects of "Weather Risk" and "Orchard Risk". If the risk of fire blight can be gauged for a particular block, spray recommendations based on anticipated weather conditions might be made more cost-effectively.

2. Previous fire blight predictive systems

Several workers have attempted to develop fire blight predictive systems that are applicable to growing conditions in their areas. Mills (1955) and Luepschen et al. (1961) determined relationships between weather conditions during and immediately following bloom and the occurrence of infection. These workers were concerned with the incubation period.

Powell's (1963, 1965) predictive system for Illinois is based on heat units accumulated between the last frost and the start of bloom. It is apparently concerned with the effect of weather conditions on the production of inoculum. The system developed by Thomson and coworkers (1977, 1982) also is based on environmental factors (mean daily temperatures) as they affect presence of inoculum in blossoms. Billing's (1979, 1980) system is also based on weather conditions (mean daily temperatures and rainfall) and is concerned with production and dissemination of inoculum and the incubation period. Until now, the Billing system has been used only to analyze past epidemics; it has yet to be used to predict the occurrence of fire blight under grower conditions.

All the predictive systems now available are predicated on the assumption that fire blight is equally possible and potentially damaging in all orchards. They do not take into consideration other factors that might affect disease severity. Thus, for instance, severe fire blight rarely occurs on trees in abandoned orchards because of lack of vigor even though the weather conditions are favorable and inoculum is present. Likewise, fire blight rarely occurs on certain cultivars of apple and pear because of their resistance to the pathogen. We feel that a system taking into account orchard conditions as well as weather conditions is needed to assess the probability of occurrence of severe fire blight.

3. A predictive system that takes orchard and weather factors into consideration

In our attempt to develop an improved predictive system, we assume that both weather factors and factors affecting host susceptibility can be broken down into several components and evaluated quantitatively. Once this is done, the contribution of each factor can be used to determine the likelihood of fire blight occurrence.

Conditions that affect the occurrence of blossom blight are emphasized because they occur during a discrete period of time and because blossom blight can be prevented by timely applications of available bactericides, at least in North America. However, we recognize that, under the appropriate conditions, blossom infections can penetrate into the woody tissues of a tree, causing the death of structurally important branches or even the whole tree. Some of the factors that we consider in assessing orchard risk may not be of great importance in determining the likelihood of blossom infection occurring; rather, they are important in predicting the damage that will result, directly or indirectly, from blossom infections.

We will now list orchard and weather factors and assess their relative contributions to the incidence and severity of fire blight. In identifying and weighting the factors that affect the severity of fire blight, our experiences and judgments have been used to construct a tentative model relating orchard and weather factors to the likelihood of occurrence of fire blight. The tentative model will be compared with orchard observations and modified.

3.1. Orchard risk factors

Five characters are considered to affect the risk of fire blight in any particular orchard (Table 1). Each of the characters has been assigned a maximum numerical value that reflects our impressions of its contribution to the overall risk of fire blight occurrence and severity in a particular orchard.

3.1.1. Cultivar

The susceptibility of the scion cultivar is probably the most important factor influencing the risk of severe fire blight. The relative susceptibility of pome-fruit cultivars has been evaluated by observing the extent of natural infection in the field under a variety of growing conditions and by determining the extent of infection following artificial inoculation in the field and in the greenhouse (Aldwinckle and Preczewski, 1976). The ratings presented in Table 2 are based on composite ratings of several tests done at Geneva on apple cultivars (Aldwinckle et al., 1984). The ratings for pear cultivars are based on similar tests and observations performed by USDA personnel and on observations of R. C. Lamb and H. S. Aldwinckle at the New York State Agricultural Experiment Station, Geneva.

3.1.2. Soil

Soil type influences the severity of fire blight. Trees on heavy, poorly drained, highly acid soils are often more severely affected than similar trees on lighter, better-drained sites. This was confirmed by a series of field experiments carried out in New York orchards by Parker, Fisher and coworkers (Fisher et al., 1959; Parker et al., 1961).

Soil type appears to influence the severity of fire blight by affecting both the time and character of tree growth. On heavy, more poorly drained soils, trees grow later during the growing season and remain succulent and susceptible to *E. amylovora* for a longer period of time. In addition, there is evidence that nutrient uptake is influenced by soil drainage and pH, and that the uptake of calcium is not favored under heavy soil conditions. Data from controlled tree nutrition studies (Lewis and Kenworthy, 1962) indicate that calcium deficiencies lead to increased susceptibility to fire blight. The susceptibility of blossoms to infection also was shown to be affected by mineral nutrition (Aldwinckle and Beer, 1976).

3.1.3. Rootstock

The rootstock can affect orchard risk in several ways. Two dwarfing rootstocks, M.9 and M.26, are themselves very susceptible to damage from fire blight (Aldwinckle and Beer, 1979). If root suckers of these stocks become infected with fire blight, tree death may result from penetration of infection into the rootstock crown. In addition, the rootstock M.9 can induce increased susceptibility of the scion to fire blight (Aldwinckle et al., 1978). The M.9 and M.26 rootstocks also produce trees on which blossom clusters frequently occur on the trunk and major scaffold limbs. Infection of these clusters can cause major damage. Therefore, trees growing on M.9 and M.26 have a greater risk of suffering severe damage. Other clonal apple rootstocks have a lesser effect and seedling rootstocks have a neutral effect. Although there are several size-controlling rootstocks for pear, we are aware of no evidence that they lead to increased scion susceptibility.

3.1.4. Age and character of growth in previous years

Young trees are more susceptible to fire blight than older trees (Dueck and Quamme, 1973). One infection that penetrates 3-yr-old wood may girdle a young tree and essentially destroy it. In contrast, older trees may sustain more infections that penetrate more deeply without being damaged severely.

Soft, succulently growing shoot tissue is much more susceptible to the initiation of infection than hardened tissues. The type of shoot growth is determined by the weather, fertilization, pruning and site characteristics. An excess of nutrients or an imbalance of the major nutrients may lead to excessive shoot growth, which is susceptible to fire blight for a longer period of time. Heavy winter pruning can also lead to excessive shoot growth.

3.1.5. Previous disease

Whether fire blight occurred in a block the previous season determines if a ready source of inoculum is likely to be present the next season. In areas where fire blight is endemic, the absence of disease in a particular block the previous season does not guarantee freedom from fire blight; inoculum may originate in other nearby blocks and be disseminated over great distances by wind, rain and insects (Beer, 1979). However, the proximity of the inoculum source does affect the risk of fire blight (Schroth et al., 1974).

Examples of several hypothetical orchards with different orchard characters are evaluated for orchard risk, based on the factors just discussed, and are presented in Table 3.

3.2. Weather factors

The occurrence of fire blight is directly related to the growth of *E. amylovora*, and temperature is the most important factor affecting its growth rate (Billing, 1974). *In vitro*, the bacterium grows very slowly at 6.5 C; its growth rate increases rapidly to 18 C, and from 18-30 C, *E. amylovora* multiplies at a rapid rate. The latter range of temperatures has been observed to favor the occurrence of severe fire blight in the field.

Utilizing temperature data for the current day and rainfall data for the previous day, Billing (1980) has assessed the risk of fire blight infection (Table 4). We have simplified and rearranged her data for trial use (Table 5). In the simplification, only the maximum temperature that occurs on the day the analysis is made and rainfall data for the previous 24 hours are used to predict the weather risk of fire blight blossom infection. For the simplification, we assume that susceptible blossoms are present and if rainfall does not occur, the relative humidity will reach at least 65%.

3.3. Integration of orchard risk and weather risk to determine the overall risk of fire blight

Orchard risk of severe fire blight may be assessed at any time before or during the growing season. The weather risk for fire blight occurrence changes each day. For trial use, the two separate risks are multiplied to determine the overall risk of fire blight (Table 6). Low, medium and high assessments are assigned values of 1, 2 and 3, respectively. The product of the orchard risk value and the weather risk value is the overall risk of fire blight. Thus, a high risk orchard under high risk weather conditions yields an overall risk value of 9. The same orchard under low risk weather conditions has an overall risk of 3. A low risk orchard under low risk weather conditions has an overall risk of 1. The same orchard under high risk weather conditions has an overall risk of 3.

3.3.1. Interpretation of overall risk scores

Once the overall risk is determined, one is better able to decide whether or not a spray to control blossom infection should be applied. We have color-coded overall risk scores to reflect the degree of danger involved (Table 7). For an overall risk score of 3 or less, WHITE, an application of bactericide is not considered justified. With an overall risk score of 4, YELLOW, a bactericide spray may be worthwhile. Without the spray, some damage from fire blight is likely to occur. With an overall risk of 6, ORANGE, an application of bactericide would undoubtedly be worthwhile. Substantial fire blight blossom infection is likely to occur without this spray. With an overall risk of 9, RED, an application of bactericide should be made. Without a bactericide application, extensive fire blight that may seriously jeopardize the orchard's future productivity and existence is likely to occur. The overall risk changes as weather conditions change, and growers are advised to reassess weather risk and overall risk on a daily basis.

4. Evaluation of the proposed system

We must now determine whether the proposed system is useful as a basis for suggesting the application of sprays to control fire blight blossom infection. Data were gathered from orchards in New York during the 1982 and 1983 growing seasons. More than 100 orchard blocks were monitored each year. The numbers and locations of orchards monitored in 1983 are depicted in Figure 1. The data taken from each block are indicated in Table 8. These data will be analyzed to determine the relationships between the occurrence of fire blight and orchard risk and weather risk factors. Based on the analysis we will determine if our tentative assignment of individual risk components is appropriate or should be altered.

The data will be analyzed by the linear logistic regression method to identify orchard risk and weather risk factors strongly associated with the occurrence of fire blight. A similar method was used to analyze other pest data (Schmidtmann et al., 1983). This method also provides an estimate of the probability of fire blight occurrence in a specified orchard block. The estimate is based on the orchard risk and weather risk factors observed in the orchard block, and can be used as an index of risk for this and other orchard blocks to be observed in the future.

The logistic regression model is

$$\lambda_i = \log\,[p_i/(1-p_i)] = \Sigma_{j=1}^{k}\,\beta_j x_{ij} \text{ for } i = 1,2,\ldots,n,$$

where x_{ij} is the value of the j^{th} risk factor in the i^{th} orchard block observed, β_j is the coefficient of the j^{th} risk factor, p_i is the probability that fire blight occurs in an orchard block with risk factors equal to $x_{i1}, x_{i2},\ldots, x_{ik}$, and λ_i is the log odds or logistic transformation of p_i. The risk factors may include orchard risk factors, weather risk factors, and interactions among combinations of these. The β_j's and p_i's are unknown, and are estimated from the observed risk factors x_{ij} and responses Y_i, which are 1 if fire blight occurs in the i^{th} orchard block and 0 otherwise. The risk factors used in the logistic regression model will be selected in stepwise fashion. The stepwise logistic regression method seeks to predict the response (1 = present, 0 = absent) accurately from as few risk factors as possible. Logistic regression is a more appropriate method for this problem than either discriminant analysis or linear regression with the response as dependent variable. Discriminant analysis depends on the assumption that the risk factors have a multivariate normal distribution, with means depending on the presence or absence of fire blight, and can be affected seriously by the violation of this assumption. Linear regression is not suitable when the response variable Y_i is dichotomous (Lee, 1980). Computer analysis of the data will be performed using the program BMDPLR in the BMDP statistical package and the procedure LOGIST in the SAS statistical system (Berenson et al., 1983).

5. Concluding Remarks

We anticipate analyzing data from the 1982 and 1983 growing seasons soon. We also anticipate that additional data will be gathered and analyzed from orchards in other areas and in future years. We feel confident that by considering both orchard and weather factors, a practical fire blight predictive system will be developed.

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Table 1 - Orchard risk characters and their relative contribution to determining total orchard risk.

Code	Character	Range
C	Scion cultivar	1-5
S	Soil drainage and pH	0-2
R	Rootstock	0-1
A	Age and growth	0-1
P	Previous disease	0-2
	Total	1-11

Table 2 - Resistance ratings of apple and pear cultivars.

APPLE

Baldwin	3	Jonamac	3	R. I. Greening	4
Barry	4	Jonathan	4	Rome Beauty	4
Beacon	3	Julyred	3	Scotia	3
Ben Davis	4	Liberty	2	Sir Prize	4
Britemac	2	Lodi	4	Spartan	3
Burgundy	4	Macfree	2	Spigold	4
Carroll	2	Macoun	3	Spijon	3
Cortland	3	McIntosh	3	Stark Bounty	2
Delicious	2	Milton	3	Stark Splendor	2
Early McIntosh	2	Mollies Del.	3	St. Earliblaze	3
Empire	2	Monroe	3	Stayman	2
Freedom	3	Mutsu	4	Summerred	3
Gloster	2	Niagara	4	Twenty Ounce	4
Golden Del.	3	Northern Spy	2	Tydeman	3
Granny Smith	4	Nova Easygro	2	Viking	2
Gravenstein	3	Paulared	3	Wayne	3
Holly	3	Prima	2	Wealthy	3
Idared	4	Priscilla	2	Wellington	2
Jamba	2	Puritan	3	Williams	2
Jerseymac	3	Quinte	3	York Imperial	4
Jonagold	4	Raritan	4		

PEAR

Anjou	4	Bosc	5	Gorham	5
Bartlett	5	Clapps Favorite	5	Seckel	3

Table 3 - Examples of orchard blocks with different orchard risk values. (Codes are defined in Table 1.)

1.

Code	Character	Score
C	Bartlett/Bosc	5
S	Poorly drained	2
R	Seedling	0
A	10 yr, Excessive	1
P	Extensive	2
	Total	10
		(High Risk)

4.

Code	Character	Score
C	Idared	4
S	Moderate drainage	1
R	M. 9	1
A	6 yr, Moderate	0
P	None	0
	Total	6
		(Medium Risk)

2.

Code	Character	Score
C	Bartlett/Bosc	5
S	Good drainage	0
R	Seedling	0
A	15 yr, Moderate	0
P	None	0
	Total	5
		(Medium Risk)

5.

Code	Character	Score
C	Delicious	2
S	Poor drainage	2
R	M.M. 111	0
A	2 yr, Moderate	1
P	None	0
	Total	5
		(Medium Risk)

3.

Code	Character	Score
C	Idared	4
S	Moderate drainage	1
R	M. 9	1
A	2 yr, Moderate	1
P	Some	2
	Total	9
		(High Risk)

6.

Code	Character	Score
C	Delicious	2
S	Good drainage	0
R	M.M. 106	0
A	2 yr, Moderate	1
P	None	0
	Total	3
		(Low Risk)

Table 4 - Risk of fire blight blossom infection as a function of weather, after Billing (1980).

Daily Maximum Temperature		Rain (previous day)		
°C	°F	0	<2.5 mm	≥2.5 mm
<18	<64	-	-	Low
18-20	64-69	-	Low	Med.
21-23	70-74	Low	Med.	High
24-30	75-86	Med.	High	High

Table 5 - Risk of fire blight blossom infection as a function of weather [simplification of Billing's (1980) data for trial use].

Daily Maximum Temperature		Risk with Indicated Rain	
°C	°F	0-2.5 mm	≥ 2.5 mm
<18	<65	-	Low
18-20	65-69	Low	Med.
21-23	70-74	Med.	High
24-30	75-86	High	High

Assumptions: Open blossoms present.
If no rain, relative humidity ≥65%.

Table 6 - Overall risk of severe fire blight.

		ORCHARD RISK		
		Low (1)	Med. (2)	High (3)
WEATHER RISK	Low (1)	1	2	3
	Med. (2)	2	4	6
	High (3)	3	6	9

Table 7 - Interpretations of overall risk scores.

Risk Score	Condition	Bactericide Appication?
1-3	White	No spray; watch conditions
4	Yellow	Spray may be worthwhile
6	Orange	Spray undoubtedly worthwhile
9	Red	Spray of crucial importance

Table 8 - Data taken from each orchard during surveys of 220 orchards in New York State in 1982 and 1983.

Identifiers	Seasonal Events
Weather station name	Phenological development
Block number at station	Relative amount of bloom
Grower name	Occurrence of secondary bloom
Orchard manager	Sprays applied for fire blight
Block name	time, material, amount concentration
Orchard Descriptors	Weather data
Block area	Continuous temperature
Spacing between rows	Continuous relative humidity
Spacing within rows	Daily rainfall
Cultivar-Rootstock Combination (CRC) 1	Occurrence of blossom blight
Percent this CRC in block	Number of trees infected
Cultivar	Number of infections/tree
Rootstock	
Age	
CRC 2, CRC 3, CRC 4	
Soil drainage characters	
Inspection	
Soil survey	
Growth expectation	